

PYROLYSIS OF PLASTIC WASTE TO PRODUCE PYROLYTIC OIL AS AN ALTERNATIVE FUEL

Ahmad Tawfiequrrahman Yuliansyah^{1*}, Agus Prasetya¹, Muhammad A. A. Ramadhan¹, Rizki Laksono¹

¹ *Chemical Engineering Department, Faculty of Engineering, Universitas Gadjah Mada, Jl. Grafika No. 2 Kampus UGM, Yogyakarta 55281, Indonesia*

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ABSTRACT

The increasing amount of plastic waste often creates chronic problems to the environment. Many efforts have been made to reduce, as well as to reuse, the plastic waste. This study investigated the use of pyrolysis of plastic waste to produce fuel oil. Plastic carrier bags, considered a low-density polyethylene (LDPE), were used as feed material. A commercial natural zeolite was used as a catalyst to enhance the oil conversion. Approximately one kilogram of plastic waste was loaded into the reactor chamber and pyrolyzed. The reactor unit was equipped with an electrical heater, a temperature controller, a condenser, and a flare system. The pyrolysis process was conducted in the temperature range of 300–450°C. The experiments were ended after an hour, the time recorded from the emergence of the flare flame. The oil product was collected from the bottom of the condenser, and its volume was measured. The physical properties of oil, such as specific gravity, kinematic viscosity, gross heating value, flash point, and water content, were evaluated and compared to those of other commercial fuels. The experimental results demonstrated that the optimum temperature for pyrolysis of plastic waste was 350°C. At this temperature, the oil yield obtained was 52.6% (vol/w). In addition, the physical properties analysis results showed that the oil product's properties were relatively closer to those of kerosene than to those of other commercial fuels.

Keywords: LDPE; Oil yield; Plastic waste; Pyrolysis; Pyrolytic oil

1. INTRODUCTION

The use of plastic materials has been increasing for various purposes, such as for food/beverage containers, household appliances, and automotive parts. This is due to several advantages of plastic materials, e.g. lightweight, flexible, durable, corrosive resistant, and easy to be formed.

Polyethylene is the most common plastic used. In total, more than 80 million tons of polyethylene are produced worldwide (Piringer & Baner, 2008). It is manufactured from polymerization of ethylene, a petroleum derivative chemical. Based on its density and molecular branching, polyethylene can be categorized into several classes. Among the classes, high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), and low-density polyethylene (LDPE) are the most important in regards to their sales volume (Wikipedia, n.d.).

The widespread use of plastic-based materials has led to an increase in the amount of plastic waste. More than 30 million and 10 million tons of plastic waste were generated in the United States (US EPA, 2008) and Japan (Nishino et al., 2003), respectively. Meanwhile, it was

* Corresponding author's email: atawfieq@ugm.ac.id, Tel. +62-274-6492171, Fax. +62-274-6492172
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estimated that 5.4 million tons of plastics were wasted in Indonesia in 2008 (Ministry of Environmental of Republic Indonesia, 2008). This enormous amount of plastic waste has the potential to be an environmental problem (Fouhy, 1993); therefore, better and proper management is urgently needed.

Various attempts have been conducted dealing with plastic waste handling. The conventional ways are incineration and waste disposal in landfills. For example, in Europe, 50% of the 24.6 million tons of post-consumer plastic waste ends up in landfills, whilst 30% is recovered as energy (by incineration), and 20% is recycled (Plastics Europe, 2008). Incineration of plastic waste, together with other municipal solid waste fractions, generates heat or energy that can be utilized for other purposes. However, the process should be carefully controlled owing to its potential negative effects, such as air pollution that can cause health problems to the people in the surrounding area (Ermawati, 2011). Meanwhile, waste disposal in landfills does not solve the problem; it just temporarily localizes the problem elsewhere. The amount of plastic waste is relatively undiminished because of its difficulty in being decomposed biologically.

One of the alternatives and a promising method for waste plastic recycling is pyrolysis, which involves thermochemical decomposition of organic and synthetic materials to produce fuels at elevated temperatures without the presence of oxygen (Syamsiro et al., 2014). Several researchers have attempted a wide range of temperatures, usually 360–500°C (López et al., 2010; Sarker et al., 2012). However, to lower the operating temperature, other researchers introduced a catalyst in the pyrolysis process. Several works using various catalysts have been reported (de Marco et al., 2009; Shah et al., 2010; Escola et al., 2011). However, only a few published reports deal with the use of natural zeolite, despite its potential catalytic activity.

Indonesia has an abundant source of natural zeolites. Arryanto and his co-workers (in Wustoni et al., 2011) have reported that the deposits are distributed in some regions, such as Malang, Bogor, and Wonosari.

In the present study, the pyrolysis method with natural zeolite as the catalyst has been attempted to treat LDPE plastic wastes to obtain fuel oil. This paper evaluates the effect of temperature on pyrolysis and the catalytic effect of natural zeolite on the yield and physical properties of the oil.

2. EXPERIMENTAL

2.1. Materials

Plastic carrier (bag) waste, considered as an LDPE, was collected from a temporary waste disposal of a central market in Yogyakarta. Prior to use, this waste was cleaned and rinsed with water to remove any particulate solids. Then, the plastic bags were air dried and cut into pieces with an approximately uniform size of 10×10 cm. For the catalytic process, natural zeolite was used as a catalyst. It was obtained from a local chemical supplier (Brataco Chemicals).

2.2. Apparatus and Experimental Procedures

Experiments were conducted in a pyrolytic reactor unit (schematically drawn in Figure 1). The unit mainly consists of a pyrolytic chamber, a catalyst bed, a condenser, and a flare system. To supply heat into the reactor, an electrical heater covering the outside surface of the pyrolytic chamber was used. A flare system was applied to burn the non-condensable gases produced from the pyrolysis reaction. In addition, three thermocouples were installed to monitor the process, e.g. one each in the pyrolytic chamber (reactor), the catalyst bed, and the exit line of condenser.

The experiment was carried out by loading 1 kg of plastic waste into the pyrolytic chamber (reactor) and 300 g of zeolites into the catalyst bed. The temperature of the pyrolytic chamber

was set to a designated temperature (300–450°C), and the electrical heater was turned on afterward. The heating was maintained for an hour, the time recorded from the appearance of the flare flame. Simultaneously, cooling water must be kept circulating over the experiment. The pyrolytic liquid product, consisting of oil and wax, was collected from the lower part of the condenser. The liquid was further cooled at room temperature, and the oil was then separated from the wax by a settling method. The volume of oil was measured and recorded. In addition, experiments without a catalyst were also done as a control. Hence, glass marbles were loaded into the catalyst holder instead of natural zeolite.

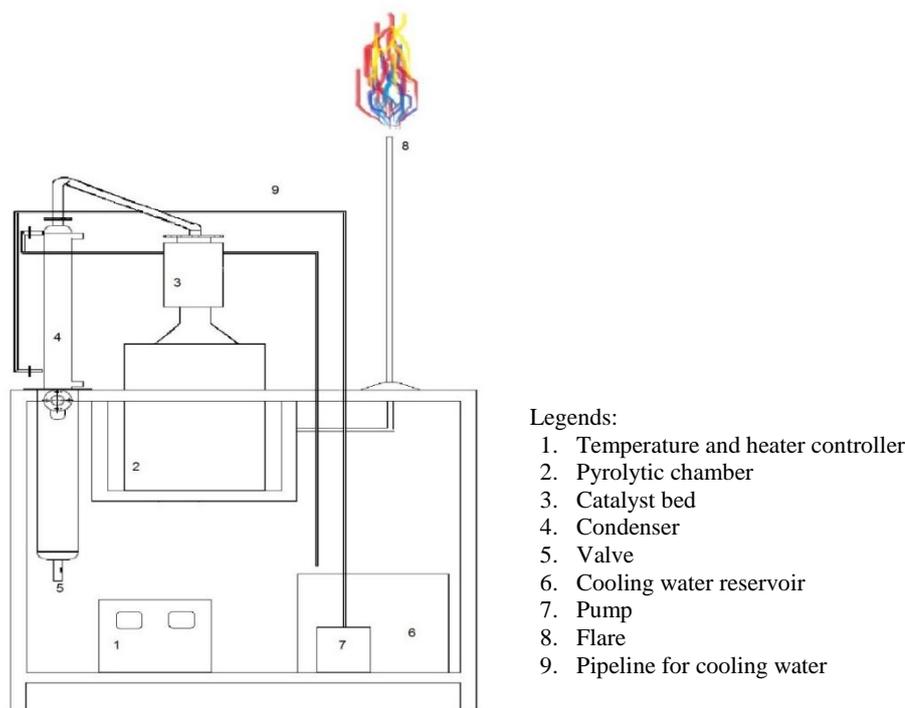


Figure 1 Experimental apparatus for pyrolysis of plastic waste

2.3. Analysis

The yield of the pyrolytic oil was evaluated as follows:

$$\text{yield (\%volume/weight)} = \frac{\text{volume of oil (ml)}}{\text{mass of plastic feed (g)}} \times 100\% \quad (1)$$

Meanwhile, the quality of the pyrolytic oil was analyzed in the Laboratory of Coal, Gas, and Petroleum Technology, Gadjah Mada University. The evaluated physical properties consisted of specific gravity at 60°F, kinematic viscosity at 30°C, flash point, and water content. The specific gravity of oil at 60°F (Sg), which compared the relative density of the oil with that of water, was measured by a hydrometer (ASTM D-1298). Meanwhile, the flash point and the water content were evaluated according to the IP-170 and D-95 methods, respectively. In addition, the gross heating value (GHV, in Btu/lb) was calculated according to Equation 2:

$$\text{GHV} = 22320 - \left(3780 \times \left(\text{Sg} \frac{60}{60^\circ\text{F}} \right)^2 \right) \quad (2)$$

3. RESULTS

The temperature profiles of the pyrolysis reactor during experiments with zeolite catalyst and without catalyst were presented in Figures 2–5 and Figures 6–8, respectively.

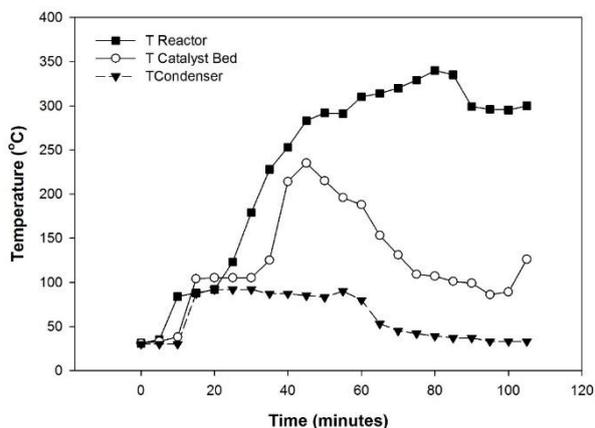


Figure 2 Temperature profile of reactor unit for 300°C experiment with zeolite catalyst

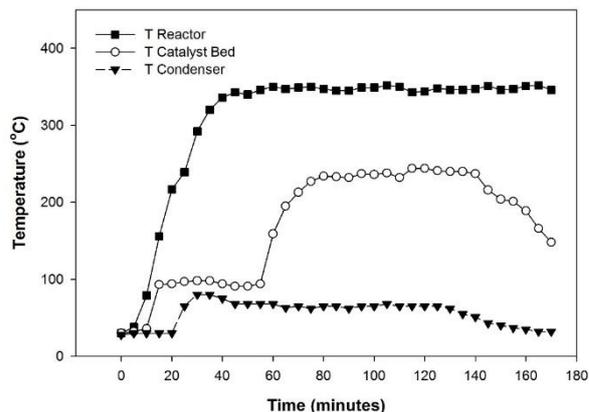


Figure 3 Temperature profile of reactor unit for 350°C experiment with zeolite catalyst

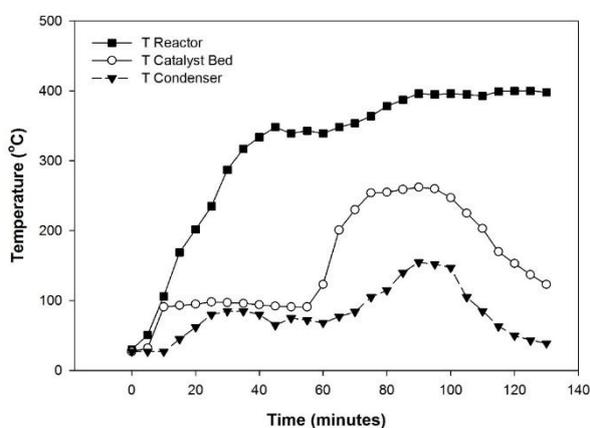


Figure 4 Temperature profile of reactor unit for 400°C experiment with zeolite catalyst

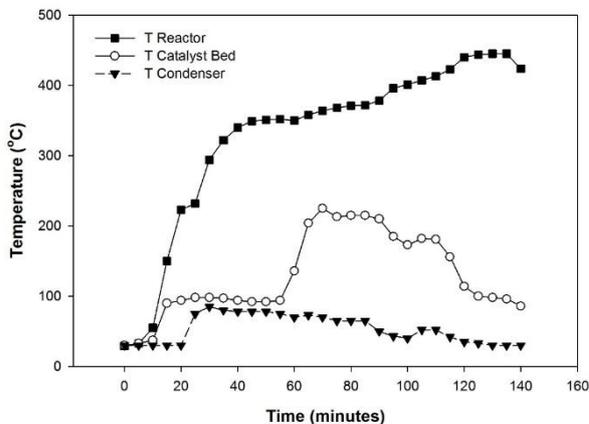


Figure 5 Temperature profile of reactor unit for 450°C experiment with zeolite catalyst

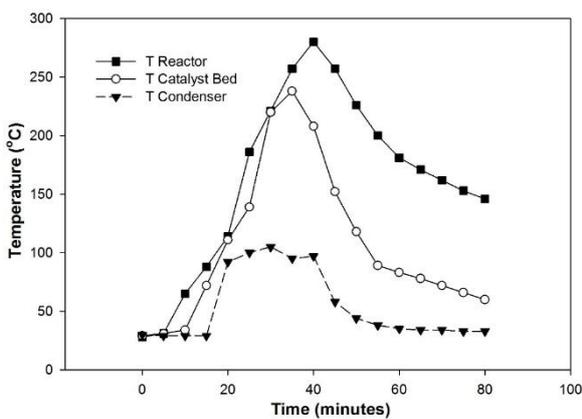


Figure 6 Temperature profile of reactor unit for 300°C experiment without catalyst

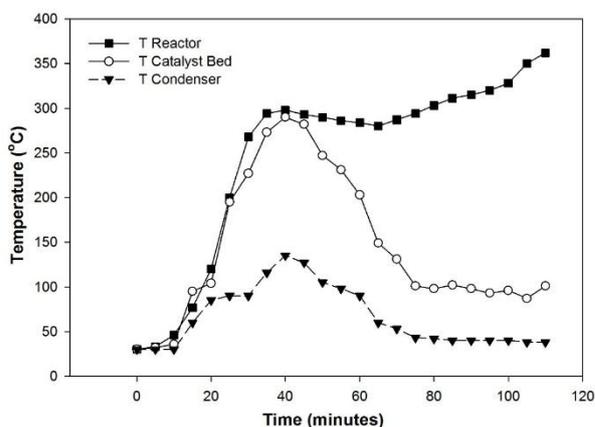


Figure 7 Temperature profile of reactor unit for 350°C experiment without catalyst

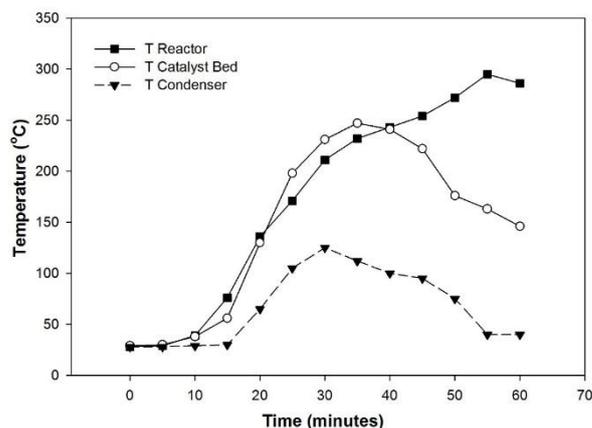


Figure 8 Temperature profile of reactor unit for 400°C experiment without catalyst

The yield of pyrolytic oil obtained from experiments was presented in Figure 9. In addition, properties of the oil were described in Table 1.

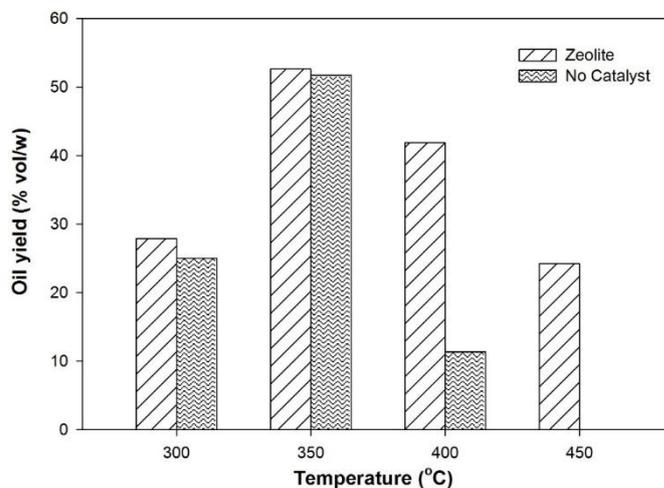


Figure 9 Oil yield obtained at various temperatures

Table 1 Properties of the oil products in comparison with properties of other commercial fuels

Sample	Parameters				
	Specific Gravity at 60°F	Gross Heating Value, Btu/lb	Viscosity at 30°C, mm ² /s	Flash Point, °C	Water Content, % vol.
Pyrolytic oil 1 (with zeolite catalyst)	0.77	20091.00	1.4	10	-
Pyrolytic oil 2 (without catalyst)	0.78	20022.00	1.7	10	-
Kerosene	0.84	20111.33	1.2	40	-
Gas Oil	0.78	19852.38	3.3	75	0.05
Diesel Oil	0.82	20304.76	2.1	55	-
HFO ^{*)}	0.95	18989.23	21.0	110	-
LFO ^{**)}	0.89	19334.49	30.0	79	0.10

4. DISCUSSION

Figures 2–8 suggested that there were temperature differences among the three zones observed. The temperature in the reactor zone was always the highest compared to that in the catalyst chamber and the condenser. This was due to the primary cracking reactions, which were very endothermic, taking place in this zone. Therefore, an electrical heater that covered the outside surface of the reactor supplied a heat flux into the reactor. High temperature was maintained to continue the cracking reactions. The heat was required to break down the polymer molecules into smaller molecules. Meanwhile, the catalyst chamber was not supplied with heat. The zeolite acted as a catalyst. It had a larger surface area to facilitate further (secondary cracking) reactions. These secondary cracking reactions were also endothermic. As a result, the temperature in the chamber was lower than that in the reactor.

In order to recover the oil product, the condenser was used to cool and to condense the products of the cracking reactions. The heat carried by the gas products was transferred to the cooling water in the condenser. Consequently, the condenser temperature dropped.

The figures demonstrated that the temperature steadily increased toward the setting temperature. Except for the 450°C experiment, this setting temperature could be reached within approximately 40 minutes for each experiment. Once the temperature was reached, it would fluctuate around this point. However, due to the limited power of the heater, the heat supplied for the 450°C experiment was not sufficient to reach and continuously maintain the setting temperature, particularly for the experiment without a catalyst. Thus, there is no data reported on this point. However, the ideal temperature profile of the experiment would be found in the 350°C experiment (Figure 3). During this experiment, the setting temperature could be maintained almost all the time.

The oil product yield from pyrolysis at various temperatures is illustrated in Figure 9. Theoretically, the oil yield increases along with the temperature, since the cracking or pyrolysis reaction rate was faster at higher temperatures. At 300°C, the thermal decomposition rate of plastic waste was still relatively slow; thus, the oil yield was only 27.9%. The oil yield was getting higher when the experiment was carried out at 350°C. Approximately 52.6% of the oil yield was collected. However, the increasing trend of the oil yield was not prolonged at temperatures over 350°C. The oil yield reduced to 41.9% and 24.2% for the 400°C and 450°C treatments, respectively. This was probably due to an excessive thermal decomposition at 400°C and 450°C. A portion of the produced oil was further decomposed into gases with low molecular weights (non-condensable). This trend was also shown in the experiments without a catalyst.

In comparison to the experiments with zeolite catalyst, the experiments without catalyst produced less oil. The difference of oil yield obtained was most clearly shown in the 400°C experiment; using zeolite produced an oil yield as high as 41.9% (vol/w), while experiments without a catalyst only generated 11.4% (vol/w). This is due to the role of the zeolite catalyst in providing a larger surface area to assist further (secondary) cracking reactions. Intermediate molecular weight products formed in the reactor were further broken down into lower molecular weight compounds on the catalyst surface and then condensed as liquid oil. Thus, since this was not facilitated in the experiment without zeolite, the oil yield became lower.

Figure 9 indicated that the best result for both cases was obtained at 350°C. Oil yield for the experiment using zeolite was 52.6% vol/w, while the experiment without a catalyst was 51.7 vol/w. This yield was comparable with other experiments carried out by several researchers (Marcilla et al., 2009; Shah et al., 2010).

Furthermore, the characteristics of this temperature's oil product have been evaluated. The analysis results are presented in Table 1.

Table 1 showed that the oil produced from pyrolysis with a zeolite catalyst has higher gross heating value and lower viscosity than that produced from the experiment without a catalyst. Since the catalyst facilitated secondary cracking reactions, it can be assumed that the oil recovered had lighter hydrocarbon fraction (lower molecular weight hydrocarbon). In general, lighter hydrocarbon fraction in a homologous series had a lower boiling point, a higher heating value, and lower viscosity.

Flash point refers to the lowest liquid temperature at which sufficient vapors are produced from the surface exposed to air to form a marginally flammable mixture (Kanury, 1983). This property is strongly related to the safety in handling the fuel. As presented in Table 1, the oil produced from catalytic pyrolysis has slightly lower specific gravity than that from non-catalytic pyrolysis. It is widely accepted that fuel with lower specific gravity has a generally lower flash point (Kanury, 1983).

According to Table 1, it was indicated that among other commercial fuels, the oil product had physical properties closer to kerosene. Compared to kerosene, the pyrolytic oil was lighter and more volatile, but slightly more viscous. In addition, both oils had a similar energy content (20022–20091 Btu/lb for pyrolytic oil vs 20111.33 Btu/lb for kerosene). Although many similarities have been found between the oil product and kerosene, more comprehensive analyses should be done if the oil were to be used as a kerosene substitute. Other oil properties, such as smoke point, sulfur content, copper strip corrosion, odor, etc, should be evaluated and meet the standard criteria for commercial kerosene.

5. CONCLUSION

Pyrolysis of plastic wastes (LDPE polymer) produced pyrolytic oil that could be considered as an alternative fuel. The physical properties of the oil were similar to that of kerosene. However, a more detailed analysis should be conducted to assure further utilization of the oil. Pyrolysis using a zeolite catalyst produced more oil than that without a catalyst. The optimum temperature for the process was 350°C, which gave a maximum oil yield as high as 52.6% vol/w (with zeolite) and 51.7% vol/w (without catalyst).

6. ACKNOWLEDGEMENT

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